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(71) Applicant
United Kingdom Atomic Energy Authority

(Incorporated in the United Kingdom)

Patents Department, Building 329, Harwell Laboratory, Oxfordshire, OX11 0RA, United Kingdom

(72) Inventor
Norma Gwynne Blamires

(74) Agent and/or Address for Service
Peter Turquand Mansfield
United Kingdom Atomic Energy Authority,
Patents Department, Building 329, Harwell Laboratory, Oxfordshire, OX11 0RA, United Kingdom

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US 4788581 A

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(54) Semiconductor dosimeter

(57) A MOSFET comprising a semiconductor substrate (10) defining doped source and drain regions (24, 26), with a gate electrode (22) separated from them by a layer of insulator or oxide (30), can be used as a dosimeter. The threshold voltage varies linearly with the dose received by the oxide layer over a wide range of doses. The sensitivity of such a dosimeter is greatly increased by implanting hydrogen ions into the oxide layer (30), subsequently maintaining the temperature of the MOSFET below 600°C. Any anneal performed after the hydrogen ion implantation is desirably at no more than 400°C.

Fig.2d.

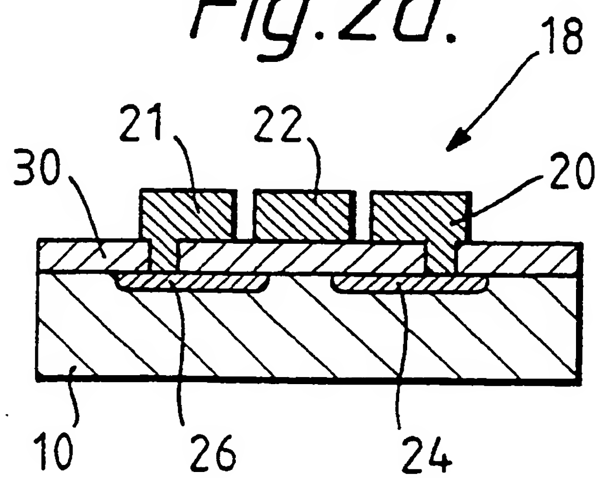

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Fig. 1.

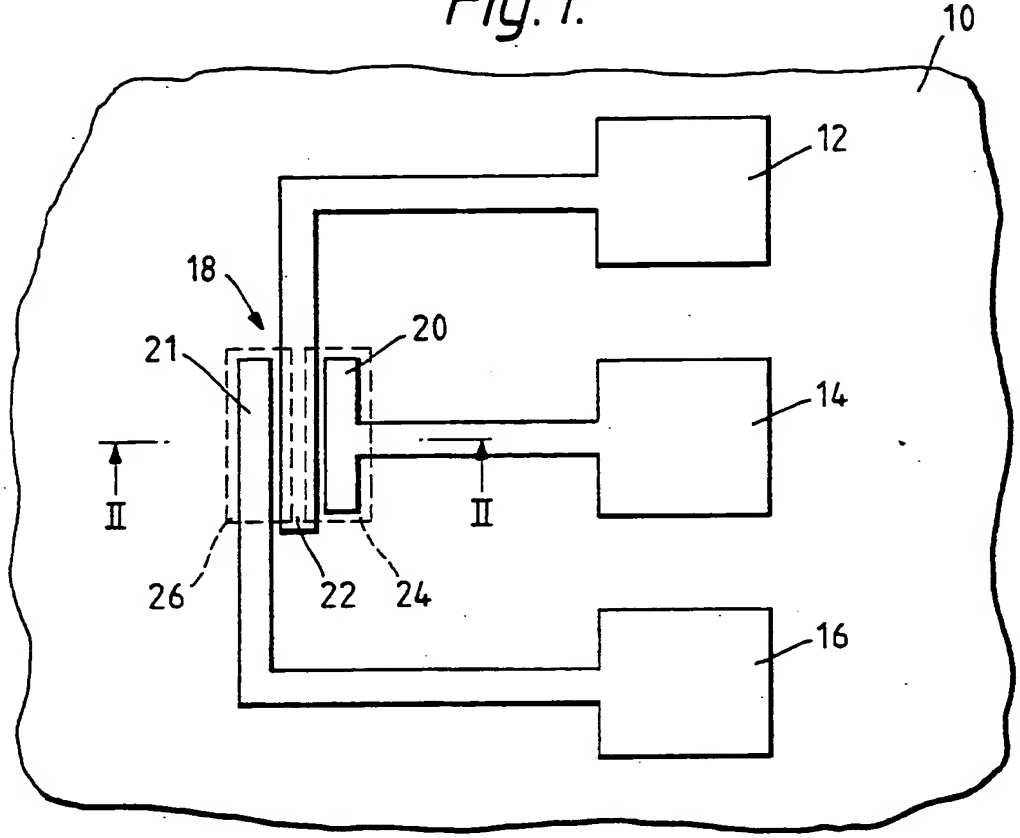


Fig. 2a.

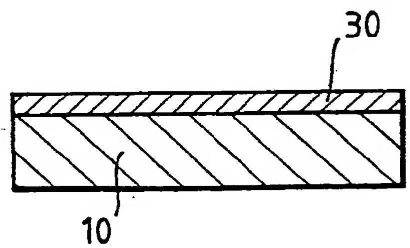


Fig. 2b.

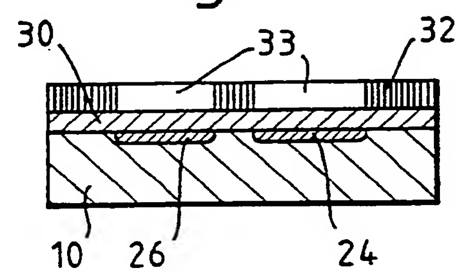


Fig. 2c.

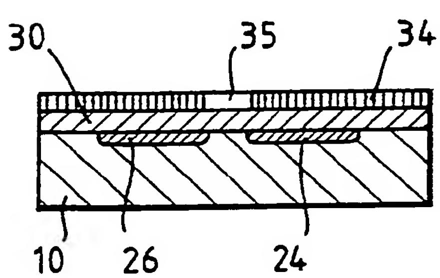
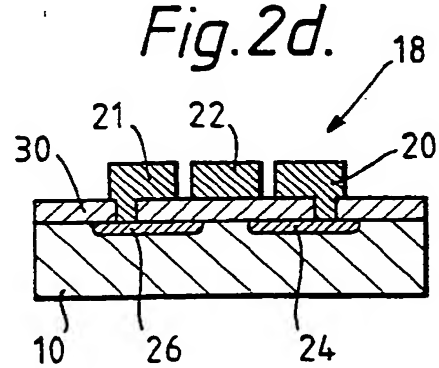


Fig. 2d.



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Semiconductor Dosimeter

This invention relates to a semiconductor dosimeter and to a method of making such a dosimeter.

It has been known for several years that a MOSFET (metal-oxide-semiconductor field-effect transistor) can be used as a dosimeter, the threshold or turn-on voltage being affected by the radiation dose to which the MOSFET is subjected. An article describing such a dosimeter by A. Holmes-Siedle and L. Adams appears in Radiat. Phys. Chem. Vol. 28 No. 2, 1986. Incident ionizing radiation generates free electrons and holes in the oxide layer of the MOSFET. An electric field in the oxide, for example due to a gate bias, causes the electrons to escape, but many of the holes are trapped in the oxide layer. It is this stored space-charge which changes the characteristic of the MOSFET, and indeed a space-charge will be developed in a similar fashion in the oxide layer in other MOS devices such as a capacitor.

According to the present invention there is provided a method of making a semiconductor dosimeter comprising a semiconductor substrate, and an electrode separated from the substrate by an insulating layer, characterized by implanting hydrogen ions into that part of the insulating layer which in the finished dosimeter is adjacent to the said electrode, and subsequently maintaining the temperature of the dosimeter below 600°C.

The preferred dosimeter is a MOSFET dosimeter in which the substrate defines a source region and a drain region, and the said electrode is a gate electrode adjacent to that part of the substrate between the source region and the drain region.

The invention also provides a dosimeter made by the above method. The MOSFET dosimeter of the invention has been found to have a much greater sensitivity than previous dosimeters, that is to say the change in threshold voltage for a given dose is much greater, by a factor of as much as five or six times. The preferred substrate is silicon, and the preferred insulating layer is of silicon dioxide. The energy of the ions is preferably chosen so that the peak concentration of implanted hydrogen is close to the interface between the silicon and the silicon dioxide layer. For example if the gate oxide is 0.3 micrometres thick, the ions are implanted at about 24 keV. The ions are preferably of hydrogen-1, but hydrogen-2 ions (deuterium ions) or even hydrogen-3 (tritium ions) might be used. The implanted dose might be between 10^{15} and 10^{17} ions cm^{-2}, but the increase in sensitivity saturates for a dose level of about 8 x 10^{15} hydrogen-1 ions cm^{-2}.

Any post-implantation heat treatment is preferably carried out at below 500°C; annealing is preferably performed at between 300°C and 500°C, most desirably at 400°C. It may be possible to dispense with post-implantation heat treatment altogether. If the dosimeter is heated to above 600°C this completely removes the increase in sensitivity due to the implantation.

The hydrogen implantation however also increases the threshold voltage, which may be disadvantageous. The increase in threshold voltage can be reduced by exposing the gate to ultraviolet light with the gate biassed positively, or by thermal annealing at between 500°C and 600°C.

The invention will now be further described by way of example only and with reference to the accompanying drawings in which:

Figure 1 shows a plan view of a MOSFET dosimeter; and

Figures 2a to 2d show a sectional view of the MOSFET dosimeter of Figure 1, along the line II-II, at successive stages in its production.

Referring to Figure 1 there is shown part of a silicon substrate 10 on whose upper surface are three aluminium terminals 12, 14, 16 of a MOSFET dosimeter 18. The terminals 14 and 16 are electrically connected by strips 20, 21 to two adjacent rectangular doped regions of the silicon substrate 10, which are the source and the drain regions 24 and 26, whose extent is indicated by broken lines. The terminal 12 is connected to a contact strip 22 which overlies the adjacent edges of the source and the drain regions 24 and 26, but is separated from them by a layer of silicon dioxide; this acts as the gate of the MOSFET.

Referring now to Figures 2a to 2d there are shown sectional views of the MOSFET 18 at successive stages in the production process. As shown in Figure 2a the n-type silicon substrate 10 is first covered on its upper surface by a layer of silicon dioxide 30; this may be grown by heating the substrate 10 with that surface exposed to oxygen. Then, as shown in Figure 2b the upper surface of the oxide 30 is covered by a layer of resist 32 leaving windows 33 above the regions to be doped. The source and drain regions 24 and 26 are then created by implanting boron ions through the windows 33 into the substrate 10 to form p^+ regions. Boron ions are implanted at an energy of typically between 100 and 200 keV (depending on the thickness of the oxide layer 30) so the peak concentration is just below the interface between the substrate 10 and

the oxide 30. The resist 32 is then removed, and the silicon 10 is annealed, typically at 900°C in an atmosphere of nitrogen for half an hour.

As shown in Figure 2c, a new layer 34 of resist is then put on the surface of the oxide 30 leaving a single rectangular window 35 above and slightly wider than the undoped strip of the substrate 10 between the two doped regions 24 and 26. The upper surface is then implanted with hydrogen ions, so hydrogen ions are implanted through the window 35 into the oxide 30; the ion energy is chosen such that the peak hydrogen concentration is just above or at the interface between the substrate 10 and the oxide 30. For an oxide thickness of 0.3 micrometres, an energy of 24 keV is suitable. An implanted dose of 8×10^{15} ions cm^{-2} is achieved. The resist layer 34 is removed and the silicon 10 annealed at 400°C in flowing nitrogen for half an hour.

Finally, referring to Figure 2d, contact slots are etched in the oxide 30 above each doped region 24 and 26. The entire upper surface is then coated with aluminium thereby filling the slots, and the silicon 10 is sintered in forming gas (nitrogen/hydrogen mixture) at 400°C for a further half an hour. This lowers the concentration of states (i.e. energy levels in the band gap) at the interface between the silicon 10 and the oxide 30. The unwanted aluminium is etched off to leave the terminals 12, 14 and 16 (as shown in Figure 1), the connecting strips 20, 21 and the gate strip 22.

In use of the MOSFET as a dosimeter, a bias voltage of for example +30 V is applied between the gate terminal 12 and the silicon substrate 10 (which is earthed). After being subjected to irradiation, for example by gamma rays, the threshold voltage on the gate terminal 12 (with the

source region 24 and the substrate 10 earthed and the drain region 26 typically at the same voltage as the gate terminal 12) at which the source/drain current is for example 10 microamps differs from its initial value prior to irradiation. The change in threshold voltage is linearly related to the dose received by the oxide layer 30 under the gate strip 22. The sensitivity of the dosimeter 18 has been found to be much greater than that of a MOSFET dosimeter made by conventional techniques without implantation of hydrogen ions into the oxide, typically about five times greater. The increase is apparently stable, showing no perceptible diminution after several months storage.

One side effect of the hydrogen implantation is to increase the threshold voltage, from about -12V without implantation, to typically -20 to -30V. During the measurement of threshold voltage the drain region 26 is usually connected to the same voltage as the gate terminal 12, and consequently the drain breakdown voltage may be exceeded. This problem could be avoided by providing the drain region 26 with its own lower voltage (e.g. -10V) supply but that is not usually convenient and so it is desirable to reduce the threshold voltage to a value in the region -10 to 20 V or less by a method that maintains the improvement in gamma sensitivity due to the hydrogen implantation. This may be achieved by exposure of the dosimeter 18 to ultraviolet radiation with the gate terminal 12 biased positively (e.g. at +30V for an oxide thickness of 0.3 micrometres) so as to inject electrons from the substrate 10 into the oxide layer 30; alternatively the threshold voltage can be reduced by thermal annealing at a temperature above 500°C but below 600°C.

The effect of the hydrogen ion implantation is not merely to increase the number of hole traps in the oxide,

as the increase in sensitivity indicates that the number of trapped holes is approximately twice the number theoretically produced in the oxide by the irradiation. Furthermore the effect is far greater than can be achieved by diffusing hydrogen into the oxide. It seems probable that there is synergy between damage to the oxide crystal structure and the presence of hydrogen ions.

Claims

1. A method of making a semiconductor dosimeter comprising a semiconductor substrate, and an electrode separated from the substrate by an insulating layer, characterized by implanting hydrogen ions into that part of the insulating layer which in the finished dosimeter is adjacent to the said electrode, and subsequently maintaining the temperature of the dosimeter below 600°C.

2. A method as claimed in Claim 1 wherein the substrate is silicon, and the insulating layer is of silicon dioxide.

3. A method as claimed in Claim 1 or Claim 2 wherein the energy of the ions is such that the peak concentration of implanted hydrogen is close to the interface between the substrate and the insulating layer.

4. A method as claimed in Claim 3 as dependent on Claim 2, wherein the oxide layer is 0.3 micrometres thick and the ions are implanted at about 24 keV.

5. A method as claimed in any one of the preceding Claims wherein the implanted dose is between 10^{15} and 10^{17} ions cm^{-2}.

6. A method as claimed in any one of Claims 1 to 4 wherein the implanted dose is no greater than 8×10^{15} ions cm^{-2}.

7. A method as claimed in any one of the preceding Claims also including annealing, after implantation, at between 300°C and 500°C.

8. A method as claimed in any one of the preceding Claims also including exposing at least part of the electrode to ultraviolet radiation, with the electrode biassed positively.

9. A method for making a semiconductor dosimeter substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

10. A semiconductor dosimeter made by a method as claimed in any one of the preceding Claims.

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Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

GB 9300324.2

Relevant Technical fields

(i) UK Cl (Edition L) H1K (KCAB, KEBA, KJAD, KLCX)

(ii) Int Cl (Edition 5) H01L

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner

R C HRADSKY

Date of Search

17 FEBRUARY 1993

Documents considered relevant following a search in respect of claims 1-10

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	US 4788581 (H M I) whole document	1

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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